Drilling Optimization Workflow

**Vibrations—Recognize the Symptoms**

**SURFACE MEASUREMENT OR SYMPTOM**
- Large WOB fluctuations
- Rig/topdrive shaking
- Loss of toolface
- Reduced ROP

**Conventional Cures While Drilling**

**AXIAL VIBRATION** (bounce)

- Increase WOB by 1 ton
- Decrease rpm by same percentage

**DOWNHOLE MEASUREMENT**
- Loss of real-time data/measurement
- Increased shock count
- Increased axial vibrations

**POSTRUN EVIDENCE**
- Early bearing failure
- Broken/chipped cutters and inserts—no specific location
- BHA failure

**Does vibration continue?**

- Yes
  - Pick up off bottom and allow string torque to unwind
  - Set rpm at 40 to 50% of original
  - Increase WOB by 10 to 20% of original
  - Gradually return rpm to original

- No
  - Vibration resumes?
    - Yes
      - Pick up off bottom and allow string torque to unwind
      - Set rpm at 40 to 50% of original
      - Increase WOB by 10 to 20% of original
      - Gradually return rpm to 25% below original
    - No
      - Repeat three times unless WOB limit is exceeded

**LATERAL VIBRATION** (bit/BHA whirl)

- Decrease rpm by 10%
- Increase WOB by 10%

**DOWNHOLE MEASUREMENT**
- Increased mean downhole torque
- High-frequency downhole shocks—10 to 50 Hz
- Increased lateral shocks
- Increased torsional acceleration
- Loss of real-time data/measurement
- Increased shock count

**POSTRUN EVIDENCE**
- Cutters/inserts damaged typically on shoulder or gauge
- Broken PDC blades
- Worn hybrids (equivalents) with minimal cutter wear
- Overgauge hole from calipers
- One-sided wear on stabilizers and BHA
- BHA failure

**Does vibration continue?**

- Yes
  - Pick up off bottom and allow string torque to unwind
  - Restart drilling with 70 rpm
  - Increase WOB by 10% of original
  - Increase rpm to original value

- No
  - Vibration resumes?
    - Yes
      - Pick up off bottom and allow string torque to unwind
      - Restart drilling with 70 rpm
      - Increase WOB to 25% below original value
      - Increase rpm to 25% below original value
    - No
      - Repeat three times unless WOB limit is exceeded

**TORSIONAL VIBRATION** (stick/slip)

- Place topdrive in high gear; ensure soft torque operational.
- Decrease WOB by 5%
- Increase rpm by 10%

**DOWNHOLE MEASUREMENT**
- Increased delta downhole torque
- Increased torsional acceleration
- Increased stick/slip indicator
- Downhole collar rpm greater than surface rpm
- Loss of real-time data/measurement
- Increased lateral shocks
- Increased shock count

**POSTRUN EVIDENCE**
- Cutters/inserts damaged typically on nose and taper
- Overtorqued connections
- Twistoffs and washouts
- BHA failure

**Does vibration continue?**

- Yes
  - Pick up off bottom and allow string torque to unwind
  - Restart drilling with 10% increased rpm
  - Decrease WOB 15 to 20%
  - Gradually return rpm to 15% above original

- No
  - Vibration resumes?
    - Yes
      - Repeat three times unless WOB limit is exceeded
    - No
      - Repeat three times unless WOB limit is exceeded
### Shock and Vibration Information

<table>
<thead>
<tr>
<th>Mode of Vibration</th>
<th>Real-Time Diagnosis</th>
<th>Typical Environment</th>
<th>Potential Cure</th>
<th>Other Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial shocks</td>
<td>Tophones or Kelly shaking, downhole</td>
<td>Hard formations, vertical holes, roller cone bits,</td>
<td>Change WOB and increase rpm</td>
<td></td>
</tr>
<tr>
<td>Bit whirl</td>
<td>LWD caliper shows overgauge hole but</td>
<td>Aggressive side-cutting bit</td>
<td>Change bit, use full-gauge bit</td>
<td></td>
</tr>
<tr>
<td>BHA whirl</td>
<td>Large downhole shocks, increased STOR</td>
<td>Washed out hole, BHA pendulum or unstabilized</td>
<td>Increase WOB and decrease rpm</td>
<td></td>
</tr>
<tr>
<td>Stick/slip</td>
<td>Large surface torque and rpm</td>
<td>Aggressive PDC bits, high wellbore BHA friction</td>
<td>Increase mud flowability, use less-aggressive bit,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fluctuations, MWD peak-peak rpm</td>
<td></td>
<td>improve hole cleaning</td>
<td></td>
</tr>
</tbody>
</table>

#### DRILLING DYNAMIC GUIDELINES

**Lateral vibration, gₚ RMS (cumulative during a bit run)**

<table>
<thead>
<tr>
<th>Vib Lat (gₚ RMS)</th>
<th>Risk</th>
<th>Time limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>1–3</td>
<td>Medium</td>
<td>Recommended to mitigate. More than 24 h, medium risk of tool failure.</td>
</tr>
<tr>
<td>3–6</td>
<td>High</td>
<td>Mandatory to mitigate. More than 12 h, high risk of tool failure.</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>Severe</td>
<td>30 minutes (formal notification)</td>
</tr>
</tbody>
</table>

**Lateral vibration, gₚ RMS (cumulative during a bit run)**

<table>
<thead>
<tr>
<th>Vib X (gₚ RMS)</th>
<th>Risk</th>
<th>Time limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>1–2</td>
<td>Medium</td>
<td>Recommended to mitigate. More than 24 h, medium risk of tool failure.</td>
</tr>
<tr>
<td>2–4</td>
<td>High</td>
<td>Mandatory to mitigate. More than 12 h, high risk of tool failure.</td>
</tr>
<tr>
<td>&gt; 4</td>
<td>Severe</td>
<td>30 minutes (formal notification)</td>
</tr>
</tbody>
</table>

#### FACTORS AFFECTING VIBRATIONS

Generalizations only—vibrations often result from complex interplay of factors

- **Inclination**—more axial vibrations closer to vertical; tendency for more vibrations as angle increases, but can also be dampened by angle
- **BHA design**—higher vibrations with slick and pendulum assemblies
- **BHA components**—undergauge stabilization generates vibrations; straight-blade stabilizers, smaller drill collars usually have higher vibrations; high-torque and aggressive mud motors may have higher vibrations
- **Bits**—PDC bits generate higher vibrations, as do aggressive features like larger cutter size, lower number of cutters, fewer blades, and low backrake angle
- **Higher friction factors** will generate higher vibrations
- **Expect higher vibrations** in formations that are hard/abrasive and/or have high coefficients of friction and restitution—conglomerates, boulders, cherts, interbedded/intercalated formations, sandstones, and limestones
- **Large ratio of hole size to BHA/tool OD size** will generate more vibrations
- **Poor hole conditions**, such as poor hole cleaning, washouts, and ledges, can sometimes generate vibrations

#### SHOCK RISK INFORMATION

<table>
<thead>
<tr>
<th>PowerPulse, TeleScope, ImPulse, LWD, and RSS tools</th>
<th>Total shock levels (cumulative only reset after appropriate tool service levels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shock risk</td>
<td>Risk level</td>
</tr>
<tr>
<td>0</td>
<td>No risk</td>
</tr>
<tr>
<td>1</td>
<td>Medium risk</td>
</tr>
<tr>
<td>2</td>
<td>High risk</td>
</tr>
<tr>
<td>3</td>
<td>Risk of tool failure</td>
</tr>
</tbody>
</table>
**Shock and Vibration Mitigation**

**VIBRATION PREVENTION**

- **Run DOX software/BHA-V**—This software analyzes BHA and predicts resonant frequencies—stay away from bad rpm; compare calculated with actual values

- **Always run multivibration chassis (MVC) in MWD tools** for real-time vibration communication

- **Within limitations, design BHA**, especially stabilization, and select PDC bit with vibration prevention in mind

- **Help train drillers** in vibration reduction—ensure LWD engineers have vibration training

- **Be aware of high-vibration operations**—backreaming, opening a pilot hole, reaming, hole opening while drilling, drilling out of casing/liner

- **Know vibration reduction procedures** for each type of vibration

- **Know procedures for dealing with high vibrations** from drilling hard streaks and reaming

- **Identify vibration generation mechanism**—bit, BHA, formation, drilling parameters, on or off bottom—and use counteractive measures

- **Optimize correct real-time shock/vibration variables** from MWD tool for predicted vibration environment

- **Set tight alarms on all vibration variables** and monitor closely—display for driller to see

- **Optimize drilling parameters**—WOB, rpm, flow rate—for vibration prevention/reduction and ROP

- **Torque feedback**—soft-torque system (may mask stick/slip)

- **Increase mud lubricity to reduce friction** and, thereby, vibrations

- **Keep offset log of formations if available**—track lithology for upcoming vibration risks

<table>
<thead>
<tr>
<th>Size, in</th>
<th>Flow Area, in², with Number of Jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>0.038 0.075 0.113 0.150 0.188 0.225 0.263 0.301 0.338</td>
</tr>
<tr>
<td>3/8</td>
<td>0.049 0.098 0.147 0.196 0.245 0.295 0.344 0.393 0.442</td>
</tr>
<tr>
<td>7/32</td>
<td>0.062 0.124 0.186 0.249 0.311 0.373 0.435 0.497 0.559</td>
</tr>
<tr>
<td>13/64</td>
<td>0.077 0.153 0.230 0.307 0.383 0.460 0.537 0.614 0.690</td>
</tr>
<tr>
<td>15/64</td>
<td>0.093 0.186 0.278 0.371 0.464 0.557 0.650 0.742 0.835</td>
</tr>
<tr>
<td>25/128</td>
<td>0.110 0.221 0.331 0.442 0.552 0.663 0.773 0.884 0.994</td>
</tr>
<tr>
<td>27/128</td>
<td>0.130 0.259 0.389 0.518 0.648 0.778 0.907 1.037 1.167</td>
</tr>
<tr>
<td>37/128</td>
<td>0.150 0.301 0.451 0.601 0.752 0.902 1.052 1.203 1.353</td>
</tr>
<tr>
<td>39/128</td>
<td>0.173 0.345 0.518 0.690 0.863 1.035 1.208 1.381 1.553</td>
</tr>
<tr>
<td>49/128</td>
<td>0.196 0.393 0.589 0.785 0.982 1.178 1.374 1.571 1.767</td>
</tr>
<tr>
<td>51/128</td>
<td>0.222 0.443 0.665 0.887 1.108 1.330 1.552 1.773 1.995</td>
</tr>
<tr>
<td>73/128</td>
<td>0.249 0.497 0.746 0.994 1.243 1.491 1.740 1.988 2.237</td>
</tr>
<tr>
<td>75/128</td>
<td>0.277 0.554 0.831 1.108 1.384 1.661 1.938 2.215 2.492</td>
</tr>
<tr>
<td>97/128</td>
<td>0.307 0.614 0.920 1.227 1.534 1.841 2.148 2.454 2.761</td>
</tr>
<tr>
<td>119/128</td>
<td>0.371 0.742 1.114 1.485 1.856 2.227 2.599 2.970 3.341</td>
</tr>
</tbody>
</table>